

## Integrated Weed Management in Mustard (*Brassica juncea* L.) – A Review

### ABSTRACT

Mustard (*Brassica juncea* L.), a species of the cruciferous family, is the world's third most significant oilseed crop, following soybean and palm. The oil content of mustard seeds ranges from 37 to 49%. India is the world's fourth largest producer of rapeseed and mustard. Weed management is the most serious problem that causes mustard's low yield. Weeds produce a substantial decrease in the yield of crops, ranging from 15-30% to complete failure of the mustard crop. Weeds compete with crop plants for water, space, sunlight, and nutrients. Weeds also reduce the quality of produce and cause a variety of health and environmental risks. Weed competition in mustard crops is especially significant early on because the crop grows slowly for the first 4-8 weeks following sowing. However, the essential period for crop-weed competition lasts 15-40 days. To optimize mustard growth and yield, weed management must be done on a timely and proper basis. The traditional practice of handweeding once during the early stages of crop growth, *i.e.*, 25-30 days after sowing, is not enough because new flushes of weeds appear after every manual weeding, irrigation, or winter rainfall, and most importantly, they drain a significant portion of the soil's nutrients and moisture. However, hand weeding in mustard is though easy but unavailability of labours at right time coupled with high wage makes it costly besides, several intra row weeds remains uncontrolled. Whereashigh dosage and frequently use of herbicides, weeds may get tolerate herbicides Thus, integrated methods may be the best option to control the complex weed flora in mustard.

**Key words:** Weed management, Weed competition, Mustard, Manual weeding and Weed flora.

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### INTRODUCTION

Oilseeds form the second major agricultural commodity after cereals in India. It accounts for about 5% of gross national product and about 10 % value of all agricultural products (Rai *et al.*, 2014). Mustard is one of the most substantial oilseed crop of global economic importance. It belongs to the family Cruciferae. Among the seven edible oilseeds cultivated in India, it is the 2nd major oilseed crop of India, ranking after groundnut. Rapeseed-mustard comprising eight different species are cultivated viz. Indian mustard (*Brassica juncea*), brown sarson (*Brassica campestris* var. brown sarson), yellow sarson (*Brassica campestris* var. yellow sarson), toria (*Brassica campestris* var. toria), gobhi sarson (*Brassica napus*), black mustard (*Brassica nigra*), karan rai (*Brassica carinata*) and rocket salad or taramira (*Eruca sativa*) are

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being cultivated in 53 countries spreading all over the globe. Indian mustard (*Brassica juncea*) alone occupies 75 per cent of the total area among brassicas grown in India.

The oil content in mustard varies from 37-49 per cent (Bhowmik *et al.*, 2014). The oil is utilized for human consumption throughout the northern India for cooking purposes. It is also used in the preparation of hair oils and medicines. It is used in the manufacture of greases. The seed is used as condiment. The leaves of young plants are used as green vegetables, as it supplies sulphur and minerals in the diet. Oil cake is used as feed and manure. Green stem and leaves are a good source of green fodder for cattle. The oil-cake contains sinigrin that causes palatability problem due to its bitter taste and glucosinolate that limits its use as a protein supplement. In the tanning industry, mustard oil is used for softening leather.

In spite of being one of the leading oilseeds producing countries, India with its vast population, it is unable to meet the requirement of edible oils. India is spending valuable foreign exchange for importing edible oils to meet the demand. For bridging gap between demand and supply, productivity needs to be enhanced. Weeds are the major biotic stress in mustard production. Weed competition in mustard is more serious during early stage because crop growth remains slow during the first 4-6 weeks after sowing. However, during later stages it grows vigorously and has suppressing effect on weeds. Weeds compete with crop for water, nutrients and light which effect growth and development of crop. Hence, there is need to remove weeds in the early stage of crop growth to avoid competition. The most common weeds that grow in rapeseed mustard are *Avena ludoviciana*, *Phalaris minor*, *Chenopodium album*, *Rumex dentatus*, *Anagallis arvensis*, *Convolvulus arvensis*, *Melilotus indica* and *Cirsium arvensis* (Singh and Kumar, 2020). The critical period of crop weed competition in mustard is 15-40 DAS and weeds cause about 25-50 % of yield loss (Yadav *et al.*, 2017) depending on weed flora, intensity and stage of the crop. In mustard hand weeding is the traditional practice. But increasing wages, scarcity of labour at peak periods and high-cost involvement compels to depend on other alternatives which are technically feasible and economically viable weed management to get optimum yield. Keeping this in view, this review work has been made with the following objectives:

1. To study the effect of weed management practices on crop growth and yield of mustard.
2. To find out the effect of weed management practices on weed control in mustard.
3. To find out the economically viable weed management practice in mustard.

## **YIELD LOSSES CAUSED BY WEEDS**

Singh *et al.* (2000) reported that infestation of *Asphodelus tenuifolius*, *Chenopodium album* and *Chenopodium murale* in mustard crop reduced the yield to an extent of 30 per cent. Gupta (2000) noticed that the seed yield of mustard was severely affected by *Chenopodium album* (45.34%) followed by *Fumaria parviflora* (43.32%) and *Convolvulus arvensis* (40.60%). Bhojar and Yaduraju (2000) found that *Asphodelus tenuifolius* is one of the primary reasons of low productivity of mustard and is known to reduce yield upto 56 per cent. Banga and Yadav (2001) realized the yield losses to the tune of 58 % due to crop-weed competition in rapeseed and mustard. A yield reduction of about 25-45 per cent was noticed depending on the type of weed flora and their intensity, stage, nature and duration of crop-weed competition in mustard (Singh *et al.*, 2001).

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Banga *et al.* (2004) examined that weed growing throughout the crop season resulted in 24.7% reduction in seed yield of mustard. Similarly, Purna *et al.* (2006) observed that presence of weeds throughout growing period resulted in 36-42 per cent reduction in seed yield of mustard. O'Donovan *et al.* (2007) estimated that yield depression in rapeseed mustard due to weed infestation varied from 20-70% depending on the composition and density of weed flora and time of their occurrence. Similarly, Chopra and Saini (2007) opined that yield loss ranged from 23-70% depending upon the type, intensity and duration of competition in gobhi sarson. Infestation of weeds in rapeseed crop causes 20-30% yield reduction (Punia *et al.*, 2010). Under unweeded condition, mustard yield reduced by 68% as compared to weed free condition (Degra *et al.*, 2011). An average yield reduction in Indian mustard was about 25.8 per cent due to weed infestation as reported by Singh *et al.* (2012). Many biotic stresses such as weeds cause severe yield losses up to 45% in rapeseed-mustard (Singh *et al.*, 2013). Koure *et al.* (2013) noticed that an average yield reduction in mustard ranged from 20-40% due to infestation of weed. The presence of weeds throughout the growing season brought about 24-50% reduction in crop yield as compared to weed free in mustard crop (Yadav *et al.*, 2017).

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## **EFFECT OF WEED MANAGEMENT PRACTICES ON WEED PARAMETERS IN MUSTARD**

### **Weed Flora**

The major weeds observed in experimental field were *Chenopodium album*, *Chenopodium murale*, *Melilotus indica*, *Cichorium intybus*, *Coronopus didymus*, *Spergula arvensis*, *Anagallis arvensis*, *Parthenium hysterophorus* and *Phalaris minor* (Nepalia and Jain, 2000). Mishra and Kurchania (2001) found similar weed flora *i.e.*, *Phalaris minor*, *Anagallis arvensis*, *Chenopodium album*, *Cichorium intybus*, *Medicago hispida*, *Melilotus indica*, *Melilotus alba*, *Vicia sativa*, *Convolvulus arvensis* and *Cyperus*

*rotundus*. The most prominent weeds of rapeseed were *Chenopodium album*, *Chenopodium murale*, *Anagallis arvensis*, *Convolvulus arvensis*, *Euphorbia helioscopia*, *Medicago polymorpha*, *Cynodon dactylon* and *Phalaris minor* (Bhowmik, 2003).

Banga *et al.* (2004) noted *Asphodelus tenuifolius*, *Chenopodium album*, *Avena ludoviciana* and *Phalaris minor* as major weeds in mustard crop. The predominant weeds *Medicago denticulata*, *Anagallis arvensis*, *Fumaria parviflora*, *Lathyrus aphaca* and *Vicia sativa* were noticed in mustard crop by Bazaya *et al.* (2004). Chauhan *et al.* (2005) identified *Chenopodium album*, *Convolvulus arvensis*, *Asphodelus tenuifolius*, *Melilotus indica*, *Anagallis arvensis*, *Avena fatua*, *Cynodon dactylon* and *Phalaris minor* as dominant weeds in mustard crop. *Polygonum persicaria*, *Polygonum pensylvanicum*, *Polygonum orientale*, *Stellaria media* and *Vicia sativa* were the dominant weeds in mustard experimental field reported by Sarkar *et al.* (2005). Singh (2006) noticed *Digera muricata*, *Amaranthus blitum*, *Celosia argentea*, *Heliotropium subulatum*, *Glinus lotoides* and *Cynodon dactylon* as predominant weeds in mustard crop during kharif season.

Khan *et al.* (2008) noticed *Avena fatua*, *Sorghum halepense*, *Phalaris minor*, *Convolvulus arvensis*, *Cyperus rotundus*, *Fumaria indica*, *Vicia sativa*, *Medicago denticulata*, *Rumex crispus* and *Anagallis arvensis* as weeds on large scale. Hugh *et al.* (2008) noticed the weed flora *i.e.*, *Avena fatua*, *Setaria viridis*, *Sinapis arvensis*, *Thlaspi arvense*, *Chenopodium album* and *Vaccaria hispanica* in mustard. Punia *et al.* (2010) noticed that mustard crop was seriously infested with *Asphodelus tenuifolius*, *Chenopodium album*, *Melilotus indica*, *Trigonella polycerata*, *Cynodon dactylon*, *Orobancha aegyptia*, *Carthamus oxycantha* and *Convolvulus arvensis*. The experimental field consisted of mixed flora *viz.*, *Cynodon dactylon*, *Phalaris minor*, *Anagallis arvensis*, *Cichorium intybus*, *Convolvulus arvensis*, *Coronopus didymus*, *Fumaria parviflora*, *Melilotus indica*, *Parthenium hysterophorus* and *Spergula arvensis* (Degra *et al.*, 2011). Kumaret *al.* (2012) found that the mustard field was predominantly infested with *Phalaris minor*, *Avena ludoviciana* and *Lolium temulentum*. The broadleaved weeds like *Vicia sativa*, *Coronopus didymus* and *Anagallis arvensis* as a whole constituted 26.7% of total weed flora. The weed flora observed in mustard field was *Medicago sativa*, *Anagallis arvensis*, *Trachyspermum ammi*, similarly, grassy weeds included *Cynodon dactylon* and *Poa annua* and the prominent weed among sedges was found to be *Cyperus rotundus* (Kour *et al.*, 2013).

Mukherjee (2014) revealed that *Anagallis arvensis*, *Chenopodium album*, *Convolvulus arvensis*, *Centella asiatica*, *Melilotus indica*, *Medicago polymorpha*, *Coronopus didymus*, *Oxalis latifolia* and *Vicia sativa* were the predominant weed species in mustard. The major weed flora

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examined in experimental site of mustard were *Cyperus rotundus*, *Anagallis arvensis*, *Chenopodium album*, *Polygonum plebejum* and *Phalaris minor* as reported by Kumar *et al.* (2015). Das (2016) examined and found that the mustard field was infested with broad leaved weeds like *Anagallis arvensis*, *Chenopodium album*, *Convolvulus arvensis*, *Fumaria parviflora*, *Melilotus alba*, *Lathyrus aphaca*, *Euphorbia hirta*, *Parthenium hysterophorus*, *Spergula arvensis*, *Gnaphalium leuteoalbum*, *Commelina benghalensis*, *Asphodelus tenuifolius*, *Cleome viscosa* and grasses like *Echinochloa colona*, *Cynodon dactylon*, *Paspalum scrobiculatum*, *Digitaria sanguinalis* and sedges like *Cyperus rotundus*.

Mustard crop was mainly infested with *Cynodon dactylon*, *Cyperus rotundus*, *Phalaris minor*, *Asphodelus tenuifolius*, *Anagallis arvensis*, *Chenopodium murale*, *Chenopodium album*, *Convolvulus arvensis*, *Fumaria parviflora* and *Melilotus indica* during rabi season as noticed by Kalita *et al.* (2017). The dominant weeds noted in the experimental field were *Phalaris minor*, *Cynodon dactylon*, *Chenopodium album*, *Anagallis arvensis*, *Melilotus alba*, *Vicia hirsuta*, *Lathyrus asphaca* and *Cyperus rotundus* (Yadav *et al.*, 2017). Jangir *et al.* (2018) noticed from Navsari, Gujarat that the experimental field was mainly infested with monocot weeds viz., *Echinochloa crusgalli*, *Digitaria sanguinalis*, *Eragrostis barbinodis* and *Cynodon dactylon*. Dicot weeds viz., *Convolvulus arvensis*, *Digera arvensis*, *Achyranthes aspera*, *Achyranthes sessilis*, *Corchorus triflorus*, *Abutilon indicum* and *Boerhavia diffusa*.

Suryavanshi *et al.* (2018) realised that mustard crop was seriously infested with *Medicago sativa*, *Sonchus arvensis*, *Cichorium intybus* and *Physalis minima*. The predominant weeds observed were *Chenopodium album*, *Thithonia diversifolia*, *Anagallis arvensis*, *Melilotus alba*, *Cyperus rotundus* and *Cynodon dactylon* in mustard during the two years of study reported by Gupta *et al.* (2018). The most dominant weed species observed was *Anagallis arvensis*, *Chenopodium album*, *Convolvulus arvensis*, *Centella asiatica*, *Melilotus indica*, *Melilotus alba*, *Medicago polymorpha*, *Coronopus didymus*, *Oxalis latifolia* and *Vicia sativa* (Chatterjee and Singh, 2018).

The pre-dominant weeds noted in the experimental field was *Phalaris minor*, *Chenopodium album*, *Anagallis arvensis*, *Melilotus alba*, *Vicia hirsuta*, *Lathyrus aphaca* and *Cyperus rotundus* (Rajet *et al.*, 2020). Singh and Kumar (2020) in mustard crop noticed *Avena ludoviciana*, *Phalaris minor*, *Chenopodium album*, *Rumex dentatus*, *Anagallis arvensis*, *Convolvulus arvensis*, *Melilotus indica* and *Cirsium arvense* as important weeds. Sharma *et al.* (2021) reported that Crop heavily infested with mixed flora of monocot and dicot weeds, viz. *Cynodon dactylon* and *Cyperus rotundus* among monocot weeds and *Coronopus didymus* and *Chenopodium album* among dicot weeds.

### Critical Crop Weed Competition

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Kondap and Upadhyay (1985) stated that critical period of crop weed competition existed up to 5 to 6 weeks after sowing the rapeseed and mustard crops under Hyderabad condition. Dashora *et al.* (1990) reported that the period upto 30 DAS was more critical for weed crop competition in mustard. Hence, it is necessary to remove weeds either manually or by using herbicides during that period. Ali (1993) realized that maintaining weed free condition beyond 40 DAS did not show beneficial and the critical period of crop-weed competition was first 8 weeks after sowing. Chauhan *et al.* (2005) observed that weed competition in mustard is more serious in early stage because crop growth during *rabi* season remains slow during the first 4-6 weeks after sowing and later it grows vigorously and suppressing effectively. The critical period of cropweed competition in mustard is early growth stages especially between 15–40 days after sowing in mustard as noticed by Shekhawat *et al.* (2012). Similarly, Singh *et al.* (2013) found that crop weed competition is severe during early growth stages particularly between 15-40 DAS in mustard.

### Weed Density and Weed Dry Weight

The lowest dry matter was obtained with two hand weeding and which was on par with stale seed bed (SSB) + fluchloralin 1.0 kg ha<sup>-1</sup> followed by one hand weeding at 4 WAS (Singh *et al.*, 2000). Similarly, Chandel and Saxena (2001) registered lower weed dry matter and weed density was observed with handweeding twice at 30 and 45 DAS. Chauhan *et al.* (2002) realized the lowest weed population and weed dry weight in mustard with weed free treatment which was on par with application of oxyfluorfen 0.25 kg ha<sup>-1</sup>. The lowest weed density was observed with pendimethalin 1.32 kg ha<sup>-1</sup> (PE) as compared to other weed management treatments (Marwat *et al.*, 2003). Bazaya *et al.* (2004) observed that significant reduction in population and dry matter of weeds with fluchloralin 0.70 kg a.i. ha<sup>-1</sup> followed by two hand weedings at 30 and 60 DAS.

Application of thiazopyr 120 g a.i. ha<sup>-1</sup> as pre-emergence application followed by one hand weeding reduced the density and dry weight of different weeds was noticed by Banga *et al.* (2004). The highest reduction in weed growth was registered with pre-emergence application of isoproturon 0.5 kg ha<sup>-1</sup> followed by one HW at 40 DAS and it showed statistical similarity with fluchloralin 1.0 kg ha<sup>-1</sup> + HW treatments (Degra *et al.*, 2006). Kumar *et al.* (2012) investigated an experiment during *rabi* season on silty clay soils and found that, lowest weed density and dry matter accumulation under hand weeding twice at 30 and 60 DAS followed by pendimethalin 0.75 kg ha<sup>-1</sup> (PE) *fb* isoproturon 0.75 kg ha<sup>-1</sup> (PoE).

Patel *et al.* (2013) realized the lowest weed density and weed dry matter accumulation with application of pendimethalin 0.5 kg ha<sup>-1</sup> (PE) + 1 HW at 25 DAS followed by oxadiargyl 75 g ha<sup>-1</sup> (PE) + 1 HW at 25 DAS. Application of pendimethalin 1 kg ha<sup>-1</sup> as pre-emergence significantly reduced the weed density and dry matter (Kour *et al.*, 2013). Mukherjee (2014) stated that

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significantly the lowest weed density was recorded under pendimethalin 0.75 kg ha<sup>-1</sup> + HW at 35 DAS and it was on par with the hand weeding twice during both the years of study. Pre emergence application of oxadiargyl fb clodinafop as PoE reduced the weed density significantly over the other treatments (Mankar, 2015). The minimum weed density and dry matter accumulation of weeds were registered under manual weeding (117 m<sup>-2</sup>) followed by quizalofop-p-ethyl 60 g ha<sup>-1</sup> (288 m<sup>-2</sup>) as reported by Kumar *et al.* (2015).

The lowest weed density and dry weight were observed with pendimethalin 1 kg ha<sup>-1</sup> as pre-emergence application noticed by Das (2016). Bamboriya *et al.* (2017) reported that the lowest weed density and weed biomass were noticed with fluazifop-p-butyl 0.055 kg ha<sup>-1</sup> at 10 DAS + 1 hoeing at 40 DAS being at par with fenoxaprop-p-ethyl 0.075 kg ha<sup>-1</sup> at 10 DAS + 1 hoeing at 40 DAS. Kalita *et al.* (2017) found that among weed management practices, one hand weeding treatment resulted in lower density of monocot, dicot and total weeds followed by oxadiargyl 0.09 kg ha<sup>-1</sup> and pendimethalin 0.75 kg ha<sup>-1</sup>. Significantly lower weed dry weight was registered with application of pendimethalin 30 EC 0.75 kg ha<sup>-1</sup> + imazethapyr 2 EC 0.75 kg ha<sup>-1</sup> (ready to mix) as noticed by Gupta *et al.* (2018).

Suryavanshi *et al.* (2018) noticed that the weed density and biomass of weed species were decreased significantly by the application of pendimethalin and isoproturon compared with unweeded control. Lower values of total weed population and dry weight of total weeds were registered with application of pendimethalin 1.0 kg ha<sup>-1</sup> as PE + quizalofop-p-ethyl 0.04 kg ha<sup>-1</sup> as PoE + HW and intercultivation (IC) at 40 DAS as noticed by Jangir *et al.* (2018). Chatterjee and Singh (2018) stated that application of pendimethalin 0.75 kg ha<sup>-1</sup> as PE followed by HW at 30 DAS registered lower weed density and it was at par with the hand weeding twice. Significantly lower weed density and dry matter accumulation of weeds were recorded with pendimethalin 1 kg ha<sup>-1</sup> and it was on par with pendimethalin 1 kg ha<sup>-1</sup> fb hand hoeing at 35 DAS in mustard (Singh and Kumar, 2020). Among the weed control practices, Pendimethalin 30% + imazethapyr 2% EC (RM) 1 kg ha<sup>-1</sup> as PE fb mechanical weeding at 30 DAS maintained superiority and registered lowest weed density and weed dry weight (Sanketh *et al.*, 2021).

Sharma *et al.* (2021) opined that minimum dry matter of weeds noticed with pre-emergence application of pendimethalin 38.7 CS @ 0.75 kg ha<sup>-1</sup> + HW 30 DAS followed by pendimethalin 30 EC @ 0.75 kg ha<sup>-1</sup> + HW 30 DAS. Tyagi *et al.* (2022) reported that two hand weeding at 25 and 50 DAS exhibited minimum value of weed density and dry weight which was significantly inferior over weedy treatment. It was followed by pendimethalin 30 EC 1.0 kg a.i. ha<sup>-1</sup> PE fb quizalofop 5 EC @ 60 g a.i. ha<sup>-1</sup> PoE recorded significantly lowest weed density and dry weight in comparison to rest of the herbicide treatments. Pandey *et al.* (2022) lowest weed density

and dry weight  $m^{-2}$  recorded with metribuzin (PE) @ 175 g  $ha^{-1}$  either with hand weeding at 40 DAS. Weedy check till maturity recorded significantly highest density and dry weight of weeds. Singhet *et al.* (2023) noticed that lower weed density and dry weight were recorded with pendimethalin (PE) @ 1000 g  $ha^{-1}$  + hand weeding at 40 DAS.

### **Weed Index**

Lowest weed index was recorded with application of pendimethalin 0.5 kg  $ha^{-1}$  (PE) + 1 HW at 25 DAS and oxadiargyl 75 g  $ha^{-1}$  (PE) + 1 HW at 25 DAS in mustard (Patel *et al.*, 2013). In mustard crop manual weeding recorded lower weed index followed by quizalofop-p-ethyl 60 g  $ha^{-1}$  (Kumar *et al.*, 2015). Jangir *et al.* (2018) concluded that the lowest weed index was recorded with application of pendimethalin 1 kg  $ha^{-1}$  as PE + quizalofop-p-ethyl 0.04 kg  $ha^{-1}$  as PoE + HW and intercultivation (IC) at 40 DAS and it was being at par with application of pendimethalin 1.0 kg  $ha^{-1}$  as PE + HW and IC at 40 DAS. Hand weeding twice at 20 and 40 DAS recorded lower weed index followed by pendimethalin (PE) 1000 g  $ha^{-1}$  + hand weeding at 40 DAS in mustard (Pandey *et al.*, 2019). The lowest weed index was registered with the application of paddy straw mulching 5 t  $ha^{-1}$  followed by pendimethalin 1.0 kg  $ha^{-1}$  (PE) + clodinafop 60 g  $ha^{-1}$  (PoE) (Singh and Kumar, 2020).

### **Weed Control Efficiency**

The highest weed control efficiency was recorded with application of pendimethalin 0.5 kg  $ha^{-1}$  (PE) + 1 HW at 25 DAS followed by oxadiargyl 75 g  $ha^{-1}$  (PE) + 1 HW at 25 DAS in mustard on loamy soils (Patel *et al.*, 2013). Patel *et al.* (2013a) noticed that two HW + two intercultivations at 20 and 40 DAS recorded significantly the higher weed control efficiency and it was on par with the pre-emergence application of pendimethalin at 1 kg  $ha^{-1}$  in groundnut. Kaur *et al.* (2013) reported that, maximum weed control efficiency in mustard was recorded with two hand weeding (25 and 45 DAS) followed by pendimethalin 0.75 kg  $ha^{-1}$  (PE).

Higher weed control efficiency was observed under manual weeding followed by quizalofop-ethyl 60 g  $ha^{-1}$  reported by Kumar *et al.* (2015). Das (2016) revealed that higher weed control efficiency was observed under hand weeding twice at 20 and 40 DAS followed by pendimethalin 1 kg  $ha^{-1}$  (PE) in mustard. Similarly, Kalita *et al.* (2017) realized that the highest weed control efficiency (69.5%) was recorded with one hand weeding and it was on par with oxadiargyl 0.09 kg  $ha^{-1}$  (67.01%). A field experiment was conducted in mustard during winter season on sandyloam soils and observed that higher weed control efficiency was with weed free followed by pendimethalin 1 kg  $ha^{-1}$  (PE) as noticed by Bijarnia *et al.* (2017). Yadav *et al.* (2017) laid out an experiment during *rabi* season on loamy sand and reported that, maximum weed control efficiency

was noticed with oxadiargyl 90 g ha<sup>-1</sup> (PE) in mustard crop. Pre-emergence application of pendimethalin 38.7 SC 0.75 kg ha<sup>-1</sup> *fb* hand weeding twice at 30DAS and 45 DAS registered higher weed control efficiency in mustard (Gupta *et al.*, 2018).

The highest weed control efficiency was noticed with application of pendimethalin 1 kg ha<sup>-1</sup> as PE + quizalofop-p-ethyl 0.04 kg ha<sup>-1</sup> as PoE + HW and intercultivation (IC) at 40 DAS and it was at par with application of pendimethalin 1.0 kg ha<sup>-1</sup> as PE + HW and IC at 40 DAS (Jangir *et al.*, 2018). Pandey *et al.* (2019) conducted an experiment on silty loamy soils and revealed that pendimethalin (PE) 1 kg ha<sup>-1</sup> + hand weeding at 40 DAS registered higher weed control efficiency. Singh and Kumar (2020) conducted an experiment during *rabi* season on clay loamy soils and concluded that maximum weed control efficiency was observed with application of pendimethalin 1 kg ha<sup>-1</sup> followed by pendimethalin 1 kg ha<sup>-1</sup> *fb* hand hoeing (35 DAS).

The highest **WCE** was recorded in pre-emergence application of pendimethalin 38.7 CS @ 0.75 kg ha<sup>-1</sup> + HW 30 DAS (64.04%) followed by pendimethalin 30 EC @ 0.75 kg ha<sup>-1</sup> (65.66%) (Sharma *et al.*, 2021). Yernauidet *et al.* (2021 a) reported that higher weed control efficiency was noticed with intercultivation and hand weeding at 15 and 30 DAS and it was followed by oxadiargyl 6% EC 0.09 kg ha<sup>-1</sup> PE *fb* intercultivation at 30 DAS. Bharat *et al.* (2022) reported that the higher weed control efficiency was recorded in weed free plots followed by pre-emergence application of oxyfluorfen @ 0.15 kg/ha (PE) though being at par with pendimethalin @ 1.0 kg/ha. Tyagi *et al.* (2022) revealed that application of pendimethalin 30 EC @ 1.0 kg a.i. ha<sup>-1</sup> PE *fb* quizalofop 5 EC @ 60 g a.i. ha<sup>-1</sup> PoE along with 125% RDF exhibited significantly highest weed control efficiency. Which was found statistically at par with pendimethalin 1.0 kg a.i. ha<sup>-1</sup> PE *fb* clodinafop 60 a.i. ha<sup>-1</sup> PoE.

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## **EFFECT OF WEED MANAGEMENT PRACTICES ON CROP GROWTH PARAMETERS**

Maximum plant height in mustard was observed with stale seed bed followed by fluchloralin 1.0 kg ha<sup>-1</sup> which was on par with hand weeding twice at 4 and 7 WAS (Singh *et al.*, 2000). Similarly, Sharma and Jain (2002) found that, higher leaf area, plant height and dry matter accumulation were recorded in weed free plots that was followed by hand weeding twice. Application of isoproturon 0.75 kg ha<sup>-1</sup> as pre-emergence along with hand weeding at 25 DAS recorded maximum plant height and leaf area (Yadav, 2004). Sewak *et al.* (2004) recorded maximum plant height and dry weight of mustard with metribuzin 0.175 kg ha<sup>-1</sup> (PE) followed by hand weeding at 30 DAS compared to weedy check. Significantly higher leaf area and dry matter accumulation in mustard were recorded with two hand weedings at 25 and 50 DAS and it was on par with integration of one HW at 25 DAS with fluchloralin 1.0 kg ha<sup>-1</sup> (Singh,

2006). Chaitanya (2010) noted that pre-emergence application of pendimethalin  $1.0 \text{ kg ha}^{-1}$  in combination with quizalofop-p-ethyl  $150 \text{ g ha}^{-1}$  at 20 DAS recorded significantly higher total dry matter production in groundnut as compared to other treatments.

Degra *et al.* (2011) revealed that two hand weedings at 25 and 45 DAS was at par with fluchloralin  $1.0 \text{ kg ha}^{-1}$  + HW at 45 DAS in recording significantly higher the leaf area of mustard. Shaheenuzzamn *et al.* (2010) identified that application of s-metolachlor 960 EC  $1.0 \text{ l ha}^{-1}$  registered higher plant height in groundnut. Sah *et al.* (2013) reported that maximum plant height, number of functional leaves, LA and dry matter was observed with one HW at 30 DAS in mustard and it was on par with pendimethalin  $0.75 \text{ kg ha}^{-1}$  (PE) and oxyfluorfen  $0.125 \text{ kg ha}^{-1}$ . Patel *et al.* (2013) stated that maximum plant height and dry matter accumulation was with pendimethalin  $0.5 \text{ kg ha}^{-1}$  (PE) + 1 HW at 25 DAS followed by oxadiargyl  $75 \text{ g ha}^{-1}$  (PE) + 1 HW at 25 DAS. Maximum plant height, leaf area and dry matter accumulation were registered with oxadiargyl  $75 \text{ g ha}^{-1}$  (PE) and it was followed by oxyfluorfen (PE) (Mankar, 2015). Among the chemical weed control measures, application of pendimethalin  $1 \text{ kg ha}^{-1}$  (PE) recorded higher plant height of yellow sarson, which was at par with application of pendimethalin  $1.5 \text{ kg ha}^{-1}$  (PE), fluchloralin  $1.5 \text{ kg ha}^{-1}$  (PPI) and clodinafop  $0.06 \text{ kg ha}^{-1}$  (25-30 DAS) as noticed by Das (2016).

Yadav *et al.* (2017) conducted an experiment during *rabi* season on silty loamy soils and concluded that maximum plant height and dry matter accumulation was registered under oxadiargyl  $90 \text{ g ha}^{-1}$  (PE). The highest plant height and dry matter accumulation were noticed with application of fluazifop-p-butyl  $0.055 \text{ kg ha}^{-1}$  at 10 DAS + one hoeing at 40 DAS and followed by two hand-weedings at 20 and 40 DAS (Bamboriya *et al.*, 2017). Significantly higher plant height and dry matter accumulation were registered with weed free by pendimethalin  $1 \text{ kg ha}^{-1}$  (PE) (Bijarnia *et al.*, 2017). Gupta *et al.* (2018) concluded that two hand weedings recorded maximum plant height over other treatments. Similarly, Kumar *et al.* (2018) noticed that the highest plant height and dry matter accumulation were observed with two hand weedings at 25 and 45 DAS followed by pendimethalin at  $0.75 \text{ kg ha}^{-1}$  (PE) over the weedy check.

Singh and Kumar (2020) conducted an experiment during *rabi* season on clay loamy soils and realized higher plant height and leaf area index with application of pendimethalin  $1 \text{ kg ha}^{-1}$  + hand hoeing at 35 DAS. Chishi *et al.* (2021) noticed that pendimethalin  $750 \text{ g/ha}$  PE + one hand weeding was superior than other treatments in recording highest plant height, plant population, and dry matter. Hadke *et al.* (2021) reported that hand weeding produced significantly higher plant height, dry weight it was followed by pendimethalin 30 EC (PE) + propaquizafop 10 EC (PoE) + WH (40 DAS). Unweeded check had the lowest plant height and dry weight. Sharma *et al.* (2021) noticed that weed free treatment resulted in the highest yield attributes like number of siliquae plant<sup>-1</sup>,

number of seeds siliquae<sup>-1</sup> and number of secondary branches plant<sup>-1</sup> significantly which was followed by pendimethalin 38.7 CS @ 0.75 kg ha<sup>-1</sup> + HW 30 DAS and pendimethalin 30 EC @ 0.75 kg ha<sup>-1</sup> + HW 30 DAS respectively.

Raj *et al.* (2021) revealed that two hand weeding at 20 and 40 DAS gave higher plant height, dry matter accumulation in g/plant, leaf area index and number of primary and secondary branches/plant. It was at par with pendimethalin (PE) 1.0 kg/ha + straw mulch 5 t/ha. Dipak and Kumar (2022). observed that among the weed management treatments, the growth and yield parameters of indian mustard viz. plant height, number of primary and secondary branches per plant, dry matter weight per plant, and leaf area were obtained under three hand weeding (30 DAS, 45 DAS and 60 DAS) which was followed by pendimethalin @ 0.5 kg/ha (pre-emergence) + isoproturon @ 1.0 kg/ha (45 DAS). Ananthapadmanabhan *et al.* (2022) revealed that higher plant height, number of branches plant<sup>-1</sup>, and dry matter per plant were recorded under pendimethalin 30% EC (PE) @ 1.0 kg a.i. ha<sup>-1</sup> + Hand hoeing (20 DAS) + Hand weeding (30-35 DAS).

#### **EFFECT OF WEED MANAGEMENT PRACTICES ON YIELD ATTRIBUTES**

Higher yield attributes of mustard like number of primary branches plant<sup>-1</sup>, number of siliqua plant<sup>-1</sup> and number of seeds silqua<sup>-1</sup> were observed with stale seed bed followed by fluchloralin 1.0 kg ha<sup>-1</sup>. However, it was on par with hand weeding twice at 4 and 7 WAS and one HW at 4 WAS (Singh *et al.*, 2000). Pre-emergence application of pendimethalin 1.0 kg ha<sup>-1</sup> recorded higher number of primary branches plant<sup>-1</sup>, number of siliqua plant<sup>-1</sup> and number of seeds silqua<sup>-1</sup> and found best substitute for manual weeding where the labour costs are too high (Singh *et al.*, 2001).

Marwat *et al.* (2003) found that higher yield attributes *i.e.*, 1000-seed weight and number of seeds siliqua<sup>-1</sup> were registered with pendimethalin (PE) 1 kg ha<sup>-1</sup> followed by trifluralin. Sewak *et al.* (2004) recorded significant improvement in number of siliqua plant<sup>-1</sup>, seeds siliqua<sup>-1</sup> and test weight of mustard with metribuzin at 0.175 kg ha<sup>-1</sup> followed by hand weeding at 30 DAS compared to weedy check. Fluchloralin 0.70 kg ha<sup>-1</sup> alone or in combination with hand weeding reduced weed growth significantly and increased the yield attributes of mustard compared to control (Bazaya *et al.*, 2004). Sarkar *et al.* (2005) reported that pre-plant incorporation of fluchloralin 1.25 kg ha<sup>-1</sup> registered highest number of siliqua plant<sup>-1</sup> (72.67) over weedy check on clay loam soils of West Bengal.

Significantly higher number of branches plant<sup>-1</sup>, number of siliqua plant<sup>-1</sup>, seeds siliqua<sup>-1</sup> and test weight in mustard were recorded with two hand weedings at 25 and 50 DAS and it was on par with one HW at 25 DAS with fluchloralin 1.0 kg ha<sup>-1</sup> (PPI) (Singh, 2006). Higher number of

siliquae plant<sup>-1</sup>, seeds siliquae<sup>-1</sup> and test weight were reported with hand weeding and followed by s-metolachlor 1 1 ha<sup>-1</sup> (Shaheenuzamn *et al.*, 2010). Degra *et al.* (2011) revealed that two hand weeding at 25 and 45 DAS registered higher number of siliquae plant<sup>-1</sup>, seed siliqua<sup>-1</sup> and 1000 seed weight in mustard compared to weedy check treatment and it was on par with fluchloralin 1.0 kg ha<sup>-1</sup> (PPI) + HW at 45 DAS. Kumar *et al.* (2012) noticed higher number of siliquae plant<sup>-1</sup>, seeds siliqua<sup>-1</sup> and test weight in mustard with application of pendimethalin 0.75 kg ha<sup>-1</sup> (PE) *fb* isoproturon 0.75 kg ha<sup>-1</sup> (PoE). Highest number of branches plant<sup>-1</sup> and number of siliquae plant<sup>-1</sup> were observed under two hand weeding (25 and 45 DAS) followed by pendimethalin 0.75 kg ha<sup>-1</sup> (PE) (Kaur *et al.*, 2013).

Higher number of branches plant<sup>-1</sup> and number of siliqua plant<sup>-1</sup> were observed with oxadiargyl 90 g ha<sup>-1</sup> (PE) and it was followed by oxyfluorfen 150 g ha<sup>-1</sup> (PE) (Mankar, 2015). Yadav *et al.* (2017) noticed significantly higher number of siliquae plant<sup>-1</sup> and seed siliqua<sup>-1</sup> with oxadiargyl 90 g ha<sup>-1</sup>. Bijarnia *et al.* (2017) conducted field experiment during the winter season on loamy sand soils and confirmed that, higher number of branches plant<sup>-1</sup>, siliquae plant<sup>-1</sup> and seeds siliqua<sup>-1</sup> were registered with weed free treatments compared to others. Among different weed management treatments, oxadiargyl 0.09 kg ha<sup>-1</sup> (PE) recorded higher yield attributes such as siliquae plant<sup>-1</sup>, seeds siliqua<sup>-1</sup> and weight of 1000 seeds in mustard and it was on par with one hand weeding at 25 DAS as reported by Kalita *et al.* (2017). Bamboriya *et al.* (2017) stated that the highest yield attributes, *viz.* siliquae plant<sup>-1</sup> (297.0), seeds siliqua<sup>-1</sup> (15.5) and 1000-seed weight (4.89 g) were recorded in mustard with fluazifop-p-butyl 0.055 kg ha<sup>-1</sup> at 10 DAS + 1 hoeing at 40 DAS. Gupta *et al.* (2018) stated that among weed management practices hand weeding recorded significantly higher number of branches plant<sup>-1</sup>, siliquae plant<sup>-1</sup> and seeds siliqua<sup>-1</sup> over weedy check in mustard.

Kumar *et al.* (2018) carried out an experiment on loamy sand soils during winter and concluded that higher number of branches plant<sup>-1</sup>, siliquae plant<sup>-1</sup> and seeds siliqua<sup>-1</sup> were noticed with application of pendimethalin 0.75 kg ha<sup>-1</sup> (PE) and it was on par with two hand weeding at 25 and 45 DAS. Pandey *et al.* (2019) reported that the highest number of branches plant<sup>-1</sup> and number of siliquae plant<sup>-1</sup> were observed with pendimethalin (PE) 1000 g ha<sup>-1</sup> + paddy straw mulch 5 t ha<sup>-1</sup> at 2-3 DAS. Higher number of branches plant<sup>-1</sup>, siliquae plant<sup>-1</sup> and seeds siliqua<sup>-1</sup> were recorded under two hand weeding at 20 and 40 DAS followed by pendimethalin (PE) 1 kg ha<sup>-1</sup> + hand weeding at 30 DAS as reported by Singh *et al.* (2020). Singh and Kumar (2020) conducted an experiment during *rabi* season on clay loamy soils and noticed higher number of primary and secondary branches plant<sup>-1</sup> under weed free situation.

Higher number of yield attributes *viz.* number of siliquae plant<sup>-1</sup>, length of siliquae, seeds siliqua<sup>-1</sup> and 1000 seed weight were noted with application of pendimethalin (PE) 1 kg ha<sup>-1</sup> +

straw mulch 5 t ha<sup>-1</sup> followed by two hand weedings at 20 and 40 DAS (Raj *et al.*, 2021). Chishiet *al.*(2021) reported that Seed/silique, silique/plant, length of silique, and seed weight were recorded under pendimethalin 750 g/ha PE *fb* one hand weeding. The treatment hand weeding produced maximum length of siliquae, number of siliquae per plant, number of seeds per siliquae and test weight and which was followed by pendimethalin 30 EC (PE) + propaquizafop 10 EC (PoE) + WH (40 DAS). Unweeded check was noticed minimum yield attributes (Hadkeet *al.*, 2021). Maximum number of siliquae per plant, number of seeds per silique, 1000 seed weight, and seed weight per plant were recorded with three hand weeding (30 DAS, 45 DAS and 60 DAS) which was followed by pendimethalin @ 0.5 kg/ha (pre-emergence) + isoproturon @ 1.0 kg/ha (45 DAS)(Dipakand Kumar, 2022).

Bharat *et al.* (2022) noticed that the maximum yield attributes *viz.*, siliquae per plant, seeds per siliquae, and 1000-Seed weight were recorded in weed free plots and followed by pre - emergence application of oxyfluorfen @ 0.15 kg/ha (PE) though being at par with pendimethalin @ 1.0 kg/ha.Yernauiduet *al.* (2022) higher number of siliquae/ plant and number of seeds/silique were recorded under inter-cultivation and hand weeding at 15 and 30 DAS and it was statistically on par with oxadiargyl 0.09 kg/ha *fb* inter-cultivation at 30 DAS.Singhet *al.* (2023) reported that the number of siliquae per plants, number of seeds per siliquaea and length of silique were recoded higher under pendimethalin (PE) @ 1000 g ha<sup>-1</sup> + hand weeding at 40 DAS.

## **YIELD**

Bazayaet *al.* (2004) investigated an experiment during *rabi* on clay loamy soils and noticed that maximum seed yield was observed under polythene mulch followed by fluchloralin *fb*hand weedingsat 30 and 60 DAS.Chauhan *et al.* (2005) stated that application of oxyfluorfen 0.25 kg ha<sup>-1</sup> as pre-emergence followed by two hand weedings (25 and 40 DAS) in Indian mustard increased the seed yield over other weed control treatments. Singh (2006) conducted an experiment during *rabi* on sandy loamy soils and noticed higher seed yield with two hand weedings at 25 and 50 DAS followed by fluchloralin 0.75 kg ha<sup>-1</sup>(PPI).Khan *et al.* (2008) studied an experiment on sandy loamy soils and revealed that, application of trifluralin 1.20 kg ha<sup>-1</sup> recorded maximum seed yield of mustard and it was on par with fluazifop-p-butyl 0.26 kg ha<sup>-1</sup>.

Pre-emergence application of pendimethalin 1.0 kg ha<sup>-1</sup> in combination with quizalofop-p-ethyl 50 kg ha<sup>-1</sup> PoE recorded significantly higher pod yield as compared to hand weeding in groundnut (Chaitanya, 2010). Significantly higher seed, stover yield and harvest index of mustard were recorded under hand weeding on clay loamy soils(Shaheenuzamn *et al.*, 2010).Higher seed, stover yield and harvest index were noticed with application of pendimethalin 0.75 kg ha<sup>-1</sup> (PE) *fb* isoproturon0.75 kg ha<sup>-1</sup> (PoE) in mustard (Kumar *et al.*, 2012).Kour *et al.* (2013) registered

higher seed and stover yields with application pendimethalin 1 kg ha<sup>-1</sup> (PE) followed by fluchloralin 1 kg ha<sup>-1</sup> (PPI) in mustard. Mukherjee (2014) noticed that during first year, maximum seed yield was registered with pendimethalin 1.25 kg ha<sup>-1</sup>, and it was significantly superior over fluchloralin 0.75 kg ha<sup>-1</sup>. In second year, highest seed yield was recorded with the hand weeding twice, and was at par with pendimethalin 1.25 kg ha<sup>-1</sup>.

Among the chemical weed control measures, application of pendimethalin 1 kg ha<sup>-1</sup> (PE) recorded higher seed yield of yellow sarson, which was on par with application of clodinafop 0.06 kg ha<sup>-1</sup> (Das, 2016). Kalita *et al.* (2017) noticed that one hand weeding at 25 DAS recorded maximum seed, stover and biological yields of 2.24, 5.59 and 7.83 t ha<sup>-1</sup> respectively, and it was found statistically at par with pre-emergence application of oxadiargyl 0.09 kg ha<sup>-1</sup> (2.23, 5.46 and 7.70 t ha<sup>-1</sup>, respectively). Maximum seed and stover yields of mustard were noticed with application of fluazifop-p-butyl 0.055 kg ha<sup>-1</sup> at 10 DAS + one hoeing at 40 DAS followed by two hand-weedings at 20 and 40 DAS as reported by Bamboriya *et al.* (2017). Higher harvest index was noticed with application of pendimethalin 1 kg ha<sup>-1</sup> (PE) followed by weed free check (Bijarnia *et al.*, 2017). Gupta *et al.* (2018) conducted an experiment and concluded that, maximum seed and stover yield of mustard were recorded under one or two hand weedings followed by pre-emergence application of pendimethalin 38.7 SC 0.75 kg ha<sup>-1</sup>. Kumar *et al.* (2018) conducted an experiment on loamy sand soils during winter and stated that maximum seed and straw yield of mustard were observed with two hand weedings at 25 and 45 DAS followed by pendimethalin at 0.75 kg ha<sup>-1</sup> (PE).

Jangir *et al.* (2018) opined that the highest grain and stover yield of mustard was noticed with application of pendimethalin 1.0 kg ha<sup>-1</sup> (PE) + quizalofop-p-ethyl 0.04 kg ha<sup>-1</sup> (PoE) + HW and intercultivation (IC) at 40 DAS. The highest seed and stover yield of mustard were recorded with pendimethalin *fb* HW under conventional tillage (maize)-zero tillage (mustard residues)-zero tillage (green gram) system (Suryavanshi *et al.*, 2018). Application of oxadiargyl 0.1 kg ha<sup>-1</sup> followed by hand weeding twice at 20 and 40 DAS recorded higher seed and straw yield compared to other treatments in mustard (Chatterjee and Singh, 2018). Pandey *et al.* (2019) revealed that maximum seed and straw yield of mustard were observed with pendimethalin (PE) 1000 g ha<sup>-1</sup> + hand weeding at 40 DAS followed by pendimethalin (PE) 1000 g ha<sup>-1</sup> + paddy straw mulch 5 t ha<sup>-1</sup> at 2-3 DAS on silty loamy soils during *rabi* season. Maximum seed and stover yield and harvest index of mustard were noticed under two hand weeding at 20 and 40 DAS followed by pendimethalin (PE) 1 kg ha<sup>-1</sup> + hand weeding at 30 DAS (Singh *et al.*, 2020). Raj *et al.* (2021) reported that, maximum seed, stover yield and harvest index were observed with application

of pendimethalin (PE) 1 kg ha<sup>-1</sup> + straw mulch 5 t ha<sup>-1</sup> followed by two hand weedings at 20 and 40 DAS in mustard.

Sharma *et al.* (2021) observed that among the treatments, pre-emergence application of pendimethalin 38.7 CS @ 0.75 kg ha<sup>-1</sup> + HW 30 DAS recorded higher seed yield, straw yield and biological yield (1220, 5549 and 6769 kg ha<sup>-1</sup>) next to weed free treatment (1297, 5888 and 7185 kg ha<sup>-1</sup>). The highest seed yield, straw yield, biological yield and harvest index was obtained in the treatment of pendimethalin 30% EC (PE) @ 1.0 kg a.i ha<sup>-1</sup> + hand hoeing + hand weeding (30-35 DAS). This was followed by hand hoeing (20-25 DAS) + hand weeding @ (40-45 DAS) (Ananthapadmanabhan *et al.*, 2022). Dhruv *et al.* opined (2023) that the highest biological, seed, straw yield and harvest index of mustard were recorded under the weed free conditions which was followed by isoproturon @ 1 kg a.i ha<sup>-1</sup> (PE) + fenoxaprop-p-ethyl @ 0.75 kg a.i ha<sup>-1</sup> at 25 to 30 DAS (PoE). Lower of these values were found under weedy check.

### QUALITY PARAMETERS

The higher oil content and oil yield in mustard seed was realized with metribuzin 0.175 kg ha<sup>-1</sup> (PE) over other treatments (Sewak *et al.*, 2007). Degra *et al.* (2011) conducted an experiment and found that maximum oil content and oil yield were recorded under two hand weedings at 25 and 45 DAS followed by fluchloralin 1.0 kg ha<sup>-1</sup> + HW 45 DAS on clay loamy soils. Kumar *et al.* (2012) reported that, maximum oil content and oil yield were registered with application of pendimethalin 0.75 kg ha<sup>-1</sup> (PE) + isoproturon 0.75 kg ha<sup>-1</sup> (PoE). Sah *et al.* (2013) recorded the maximum oil content in mustard seed in one hand weeding which was at par with oxyfluorfen 0.125 kg ha<sup>-1</sup>. Application of pendimethalin 0.5 kg ha<sup>-1</sup> (PE) + 1 HW at 25 DAS realized significantly higher oil content (38.68 %) and it was statistically on par with oxadiargyl 75 kg ha<sup>-1</sup> (PE) + 1 HW at 25 DAS (Patel *et al.*, 2013).

Bamboriya *et al.* (2017) conducted an experiment on clay loamy soils during winter and concluded that maximum oil content was observed with application of fluazifop-p-butyl 0.055 kg ha<sup>-1</sup> at 10 DAS + one hoeing at 40 DAS. Singh *et al.* (2020) conducted an experiment and noticed maximum oil content with two hand weedings at 20 and 40 DAS followed by pendimethalin (PE) 1 kg ha<sup>-1</sup> + hand weeding at 30 DAS. Kumar *et al.* (2021) reported that the maximum oil content (41.07%) and oil yield (1029 kg ha<sup>-1</sup>) was recorded in two HWs at 25 and 45 DAS treatment. Being at par with two HW at 25 and 45 DAS and pendimethalin @ 0.75 kg ha<sup>-1</sup>. Oil content and oil yield was found higher in two hand weeding at 20 and 40 DAS and it was at par with pendimethalin (PE) 1.0 kg/ha + straw mulch 5 t/ha (Raj *et al.*, 2021). Dipak and Kumar (2022) reported that quality parameters *i.e.*, oil content, and protein content were recorded highest with three hand weeding (30 DAS, 45 DAS and 60 DAS) which was followed by

pendimethalin @ 0.5 kg/ha (pre-emergence) + isoproturon @ 1.0 kg/ha (45 DAS).

### **EFFECT OF INTEGRATED WEED MANAGEMENT PRACTICES ON NUTRIENT REMOVAL BY WEEDS**

Dashora *et al.* (1990) identified that uncontrolled weed growth in mustard throughout the crop season caused loss of 14.6 kg N ha<sup>-1</sup>. The nutrient depletion was higher under unweeded treatment (18.5, 4.7 and 82.2 kg ha<sup>-1</sup> NPK, respectively) and lowest under thiobencarb 1 kg ha<sup>-1</sup> as pre-emergence application at 25 DAS in mustard (Singh 1992). Minimum N and S uptake by weeds was noticed with pendimethalin + isoproturon and hand weeding twice reported by Kumar *et al.* (2012). Kour *et al.* (2013) found that, the lowest uptake of N, P and K by weeds was noticed with application pendimethalin 1 kg ha<sup>-1</sup> (PE) and followed by fluchloralin 1 kg ha<sup>-1</sup> (PPI) on sandy loamy soils.

Mukherjee (2014) realized lower depletion of N, P and K by weeds with hand weeding twice during two years of his study. However, it was found at par with pendimethalin 0.75 kg ha<sup>-1</sup> + HW at 35 DAS. Lowest N removal by weeds in mustard was observed with oxadiargyl 90 g ha<sup>-1</sup> as pre-emergence application (Yadav *et al.*, 2017). Minimum removal of N, P and K by weeds was found with application of pendimethalin 1 kg ha<sup>-1</sup> as PE + quizalofop - p - ethyl 0.04 kg ha<sup>-1</sup> as PoE + HW and intercultivation (IC) at 40 DAS and it was being at par with application of pendimethalin 1.0 kg ha<sup>-1</sup> as PE + HW and IC at 40 DAS noticed by Jangir *et al.* (2018). Similarly, minimum nutrient removal by weeds was recorded with pendimethalin (PE) 1.0 kg ha<sup>-1</sup> + straw mulch 5 t ha<sup>-1</sup> and pendimethalin (PE) 1.0 kg ha<sup>-1</sup> + hand weeding at 45 DAS (Rajet *et al.*, 2021).

### **EFFECT OF INTEGRATED WEED MANAGEMENT PRACTICES ON NUTRIENT UPTAKE BY CROP**

Singh *et al.* (1993) opined that significantly higher N, P and K uptake by mustard crop was recorded in hand weeded and herbicides treated plots than unweeded plots. Kaneria and Patel (1995) concluded that the highest N, P and K uptake in Indian mustard (122.7, 43.0 and 144.9 kg N, P and K ha<sup>-1</sup>, respectively) was recorded under two hand weeding treatments at 25 and 45 DAS in comparison to weedy check plots (51.3, 15.6 and 85.4 kg ha<sup>-1</sup> respectively). Higher uptake of N, P and K by mustard crop was recorded with hand weeding twice at 25 DAS and 45 DAS which was at par with pendimethalin as pre-emergence application (Dixit and Gautam, 1996). Nepalia and Jain (2000) at Udaipur found that oxadiargyl 0.5 kg ha<sup>-1</sup> treated plots registered the maximum uptake of N, P, K and S by mustard crop and lowest in weedy check.

Chandoliya *et al.* (2010) conducted an experiment at MPUAT, Udaipur on sandy loamy soil and found that pendimethalin and oxyfluorfen in combination with one hand weeding were the

most effective in enhancing total N and P uptake except weed freecheck in groundnut. The maximum N uptake was observed with pendimethalin 0.75 kg ha<sup>-1</sup> + isoproturon 0.75 kg ha<sup>-1</sup> being at par with oxadiargyl 0.90 kg ha<sup>-1</sup> + isoproturon 0.75 kg ha<sup>-1</sup> as noticed by Kumar *et al.* (2012). Application of pendimethalin 1 kg ha<sup>-1</sup> (PE) followed by fluchloralin 1 kg ha<sup>-1</sup> (PPI) registered higher nutrient uptake (N, P and K) by crop (Kour *et al.*, 2013). Uptake of N, P and K nutrients by mustard crop was maximum under two hand weedings at 20 and 40 DAS followed by paddy straw mulch 10 t ha<sup>-1</sup> at 2-3 DAS (Pandey *et al.*, 2019). Raj *et al.* (2021) reported that significantly higher nutrient uptake by crop recorded under two hand weedings at 20 and 40 DAS and it was at par with pendimethalin (PE) 1.0 kg/ha + straw mulch 5 t/ha. Yernaide *et al.* (2023 c) revealed that among different weed management practices, higher nutrients uptake (59.57, 24.51, 52.46 kg ha<sup>-1</sup> N, P<sub>2</sub>O<sub>5</sub>, and K<sub>2</sub>O, respectively) by crop were observed under intercultivation and hand weeding at 15 and 30 DAS and it was on par with oxadiargyl 6% EC 0.09 kg ha<sup>-1</sup> PE + intercultivation at 30 DAS.

#### **EFFECT OF INTEGRATED WEED MANAGEMENT PRACTICES ON ECONOMICS OF MUSTARD**

Singh (2006) recorded maximum net profit and B:C ratio with pre-plant incorporation of fluchloralin 0.75 kg ha<sup>-1</sup> along with one hand weeding at 25 DAS. The highest B:C ratio in groundnut (3.06) was obtained with application of oxyfluorfen 0.1 kg ha<sup>-1</sup> as pre-emergence in combination with one HW at 30 DAS, followed by pendimethalin + one HW at 30 DAS (2.98) as compared to hand weeding alone (1.63) (Chandolia *et al.*, 2010). Pre-emergence application of pendimethalin 1.0 kg ha<sup>-1</sup> in combination with quizalofop-p-ethyl 50 g ha<sup>-1</sup> PoE recorded significantly higher benefit:cost ratio (2.43) as compared to hand weeding (2.21) in groundnut (Chaitanya, 2010). Degra *et al.* (2011) stated that, higher net returns and benefit cost ratio were recorded with application of fluchloralin 1.0 kg ha<sup>-1</sup> followed by two hand weedings at 25 and 45 DAS. Maximum gross returns and net returns were observed with application of trifluralin 0.75 kg ha<sup>-1</sup> (PPI) + HW at 30 DAS (Kumar *et al.*, 2012). Application pendimethalin 0.5 kg ha<sup>-1</sup> (PE) + HW at 25 DAS and followed by oxadiargyl 75 g ha<sup>-1</sup> (PE) + 1 HW at 25 DAS resulted in higher net returns (Patel *et al.*, 2013).

Yadav *et al.* (2014) conducted a field experiment on groundnut and concluded that higher B:C ratio was obtained with the application of alachlor 1.25 kg ha<sup>-1</sup> with one HW at 6 WAS that was followed by oxyfluorfen 200 g ha<sup>-1</sup> with one HW at 6 WAS. The highest net returns (Rs19,950) were obtained with two HW treatment and was followed by pendimethalin 0.75 kg ha<sup>-1</sup> + HW at 35 DAS (Mukherjee, 2014). In mustard crop higher net returns and benefit cost ratio were noticed under manual weeding followed by quizalofop-p-ethyl 60 g ha<sup>-1</sup> as reported by Kumar *et al.* (2015). Maximum net returns were obtained with oxadiargyl PE (Rs21909 ha<sup>-1</sup>) followed by

oxyfluorfen as PE (Rs 17248 ha<sup>-1</sup>) (Mankar, 2015). The highest net returns and benefit:cost ratio (2.69) were recorded with fluazifop-p-butyl 0.055 kg ha<sup>-1</sup> at 10 DAS+ 1 hoeing at 40 DAS being at par with fenoxaprop-p-ethyl 0.075 kg ha<sup>-1</sup> at 10 DAS + 1 hoeing at 40 DAS (Bamboriya *et al.*, 2017). Kalita *et al.* (2017) realized higher net returns and B:C ratio with pre-emergence application of oxadiargyl 0.09 kg ha<sup>-1</sup> followed by one hand weeding at 25 DAS.

Suryavanshi *et al.* (2018) found that the highest gross and net returns were registered with pendimethalin 1kg ha<sup>-1</sup>/b HW and isoproturon 0.75 kg ha<sup>-1</sup> under conventional tillage (maize)-zero tillage (mustard residues). The highest B:C ratio (3.51) was obtained with application of pendimethalin 1kg ha<sup>-1</sup> as PE + quizalofop-p-ethyl 0.04 kg ha<sup>-1</sup> as PoE + HW and intercultivation (IC) at 40 DAS and it was being at par with application of pendimethalin 1.0 kg ha<sup>-1</sup> as PE + HW and IC at 40 DAS as noticed by Jangir *et al.* (2018). Maximum net returns and benefit-cost ratio were observed with application of pendimethalin 0.75 kg ha<sup>-1</sup> (PE) which was however on par with two hand weeding at 25 and 45 DAS (Kumar *et al.*, 2018). Chatterjee and Singh (2018) noticed maximum net returns and benefit-cost ratio with application of oxadiargyl 0.1 kg ha<sup>-1</sup> followed by hand weeding twice at 20 DAS and 40 DAS. Application of pendimethalin (PE) 1.0kg ha<sup>-1</sup> + hand weeding at 30 DAS obtained higher gross returns, net returns and benefit-cost ratio (Singh *et al.*, 2020).

Hadke *et al.* (2021) reported that pendimethalin 30 EC + propaquizafop 10 EC + WH (40 DAS) has a B:C ratio of 2.28, which was higher than all other treatments, followed by oxyfluorfen 23.5 EC (PE) + propaquizafop 10 EC (PoE) + WH (40 DAS). The maximum economical gain of gross returns, net returns and BCR were obtained under weed free condition which was significantly followed by isoproturon @ 1 kg a.i ha<sup>-1</sup> (PE) + fenoxaprop-p-ethyl @ 0.75 kg a.i ha<sup>-1</sup> at 25 to 30 DAS (PoE). Lower of these values were found under weedy check (Dhruv *et al.*, 2023). Maximum net returns and B:C ratio were recorded under pendimethalin (PE) @ 1000 g ha<sup>-1</sup> + hand weeding at 40 DAS (Singh *et al.*, 2023).

## **EFFECT OF INTEGRATED WEED MANAGEMENT ON SOIL ENZYMES ACTIVITY**

An experiment was conducted in rice crop and urease activity and dehydrogenase activity in butachlor treated soil showed an increasing trend from 7<sup>th</sup> day to 28<sup>th</sup> day of incubation. Similar trend was exhibited in paraquat and glyphosate treated soil. It was evident from the data that the soil treated with pyrazosulfuron had the lowest set of dehydrogenase activities as compared to other herbicides treated soil reported by (Baboo *et al.*, 2013). Panda and Raha (2016) conducted a

laboratory study and observed that glyphosate at field application dose ( $0.90 \mu\text{g g}^{-1}$ ) and double the field application dose ( $1.80 \mu\text{g g}^{-1}$ ) inhibited the Fe and Mn reduction from 5.18 to 14.35% and stimulated the soil dehydrogenase activity from 11.64 to 43.12%. However, both inhibition and stimulation effect on Fe and Mn reduction and soil dehydrogenase activity was resulted from the application of herbicides paraquat and pendimethalin at their field ( $0.45 \mu\text{g g}^{-1}$ ) and double the field application dose ( $1.41 \mu\text{g g}^{-1}$ ). Lal *et al.* (2017) observed that weed free check recorded significantly higher dehydrogenase, urease and phosphatase activity at 7 and 15 days after spraying compared to all other treatments and lower dehydrogenase, urease and phosphatase activity under imazethapyr ( $75 \text{ g ha}^{-1}$  with adjuvant) application at 7 and 15 days after spraying in green gram. Significant increase in dehydrogenase activity of all the treatments at 50 days after herbicide spray *i.e.*, peak period of crop growth was observed indicating that microbial activity was increased in maize (Varshitha *et al.*, 2019).

Pertile *et al.* (2020) conducted an experiment in soybean fields and identified that dehydrogenase activity did not vary between the treatments and the control with the application of fumioxazin in the without history of herbicides application in the field ( $H_0$ ), signifying no effect of fumioxazin on catabolic activity in the soil. However, DHA was affected by herbicides in with history of herbicides application in the field ( $H_2$ ). After the incubation, DHA increased during the first 15 days and decreased after that period to control levels. This pattern was parallel to the one observed for soil respiration and it can indicate an initial stimulation of microbial activity by the herbicides. Yernaïdu *et al.* (2023 b) noticed that higher dehydrogenase activity was observed under oxadiargyl 6 % EC  $0.09 \text{ kg ha}^{-1}$  PE fb straw mulch  $5 \text{ t ha}^{-1}$  ( $7.18 \mu\text{g TPF g}^{-1} \text{ soil day}^{-1}$ ) and it was found to be on par with oxyfluorfen 23.5 % EC  $0.1 \text{ kg ha}^{-1}$  PE fb straw mulch  $5 \text{ t ha}^{-1}$ , pendimethalin 30 % EC  $1.0 \text{ kg ha}^{-1}$  PE fb straw mulch  $5 \text{ t ha}^{-1}$ .

## EFFECT OF WEED MANAGEMENT ON ENERGETICS

Firouzi and Aminpanah (2012) observed that the total energy input and total energy output recorded was found to be 20164.36 MJ  $\text{ha}^{-1}$  and 79252.02 MJ  $\text{ha}^{-1}$  respectively for groundnut production. Energy usage ratio of 3.93 indicates the affective use of energy in groundnut production. Energy productivity was computed to be 0.212. This shows that 0.212 kg of groundnut obtained per unit energy input (MJ). Energy use efficiency, energy productivity, specific energy and net energy of dry land barley production were 5.3, 0.28 kg  $\text{MJ}^{-1}$ , 3.58 MJ  $\text{kg}^{-1}$ , 33,833.67 MJ  $\text{ha}^{-1}$  respectively. Results of this study showed that human labour as well as machinery energy inputs were the most important inputs influencing the dry land and irrigated barley production systems (Azizi and Heidari, 2013).

**Comment [H10]:** Is there any information on other important enzymes like phosphatase and arylsulphatase? Also on the effect of weed types and density on soil enzymes.

It is better to read the following articles for comparison:

Salam, A. K., Afandi, Sriyani, N., & Kimura, M. (2001). Soil enzymatic activities in a hilly coffee plantation in Lampung province, south Sumatra, Indonesia, under plant cover management. *Soil Science and Plant Nutrition*, 47(4), 695–702. <https://doi.org/10.1080/00380768.2001.10408434>

Salam, A. K., Katayama, A., & Kimura, M. (1998). Activities of some soil enzymes in different land use systems after deforestation in hilly areas of west Lampung, south Sumatra, Indonesia. *Soil Science and Plant Nutrition*, 44(1), 93–103. <https://doi.org/10.1080/00380768.1998.10414429>

Salam, A. K., Desvia, Y., Sutanto, E., Syam, T., Nugroho, S. G., & Kimura, M. (1999). Activities of soil enzymes in different land-use systems in middle terrace areas of Lampung province, South Sumatra, Indonesia. *Soil Science and Plant Nutrition*, 45(1), 89–99. <https://doi.org/10.1080/00380768.1999.10409326>

**Comment [H11]:** 20,164.36

**Comment [H12]:** 79,52.02, this notation

Alper *et al.* (2015) in his four-years of study noticed that energy indices were significantly affected by tillage systems, with no till consumed the least energy for wheat production (8.20 MJ/kg), CT consuming the most (11.74 MJ/kg for CT). NT (normal tillage) was found to be the most efficient overall tillage system of his study. However, conservation tillage of winter wheat can be used to increase productivity with only a minimum energy input. In a study conducted at PJTSAU, Rajendranagar, the results depicted that the total energy input and output energy under different weed management practices were about 16051 to 18550 and 2360 to 16838 MJ ha<sup>-1</sup> respectively. The highest energy use efficiency (0.9), energy intensiveness (0.7 MJ ₹<sup>-1</sup>), specific energy (12.9 MJ kg<sup>-1</sup>), energy productivity (0.9 kg MJ<sup>-1</sup>), net energy (-1712 MJ ha<sup>-1</sup>) of *Bt* cotton production system were reported in mechanical weeding thrice at 20, 40 and 60 DAS (Rani *et al.*, 2016).

Hanumanth (2017) observed that significantly higher energy output of kapas, total energy output, kapas energy use efficiency, total energy use efficiency, kapas energy productivity and total energy productivity was obtained under mechanical weeding thrice at 20, 40 and 60 DAS. Significantly higher energy output and energy-use efficiency were registered with zero tillage + crop residues 4 t ha<sup>-1</sup> (ZT+CR) followed by ZT+CR 2 t ha<sup>-1</sup> + hydrogel (Jakhar *et al.*, 2018). Devi *et al.* (2018) conducted an experiment during *rabi* season in wheat crop and concluded that energy use efficiency, energy profitability, energy productivity and energy intensity were higher with tank mix application of pinoxaden (50 g ha<sup>-1</sup>) followed by carfentrazone+metsulfuron-methyl (25 g ha<sup>-1</sup>) 35 days after sowing.

Significantly maximum energy output:input ratio, energy use efficiency and energy productivity were recorded under oxadiargyl 90 g ha<sup>-1</sup> (PE) *fb* penoxsulam 22.5 g ha<sup>-1</sup> (PoE) followed by pyrazosulfuron + pretilachlor 10 kg (G) ha<sup>-1</sup> (PE) *fb* bispyribac sodium 25 g ha<sup>-1</sup> (PoE) in rice crop. The lowest output energy was recorded under unweeded control reported by Bajaj *et al.* (2019). In black soil, significantly higher energy use efficiency and energy productivity of kapas and total output was recorded with diuron 0.75 kg ha<sup>-1</sup> PE *fb* pyriithiobac sodium + quizalofop-p-ethyl PoE and mechanical weeding thrice in cotton (Varsha *et al.*, 2020). Maximum energy output to input ratio, energy use efficiency and energy productivity were noticed in rice under oxadiargyl 70 g ha<sup>-1</sup> (PE) *fb* bispyribac sodium 20 g ha<sup>-1</sup> at 25 DAS (Jha *et al.*, 2020).

Kumar *et al.* (2021) opined that higher output energy (151500 MJ ha<sup>-1</sup>), output input energy ratio (13.65), energy use efficiency (0.225) and energy balance (140430 MJ ha<sup>-1</sup>) were obtained with two hand weeding at 25 and 45 DAS. Yernaide *et al.* (2023 a) noticed that maximum energy output, net energy, energy use efficiency and energy productivity were noticed under intercultivation and hand weeding at 15 and 30 DAS and it was statistically on par with Raft 6 %

EC as PE *fb* intercultivation at 30 DAS, Goal 23.5 % EC as PE *fb* intercultivation at 30 DAS and Stomp 30 % EC as PE *fb* intercultivation at 30 DAS.

## CONCLUSION

Weed interference in mustard causes substantial yield loss. Weed duration in the field has an effect on yield, as do damage thresholds, which vary according on the weed. To avoid economic losses, weed control should be practiced early in the growth period, especially over the first four to six weeks, which constitute significant periods of competition in mustard. Weed management is a system approach in which all land use planning is done advance of time to limit aggressive weed invasions and offer crop plants a competitive advantage over weeds. Weeds in mustard can be effectively controlled with pre-plant herbicides such as fluchloralin and trifluralin. Among pre-emergence herbicides, alachlor, butachlor, isoproturon, metolachlor, metribuzin, nitrofen, oxadiargyl, oxadiazon, oxyfluorfen, pendimethalin, terbutryn, and thiobencarb show potential. However, in the modern era, integrated weed management approaches are becoming increasingly significant due to their environmental benefits. Integrated management strategies involving preventive, cultural and herbicidal methods can provide an acceptable degree of weed control in mustard crop. Integration of chemical weed control with mechanical weeding is the most effective and economically viable method for weed management in mustard.

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Comment [H13]: Different notation?

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Comment [H14]: Different notation?

Comment [H15]: 2013b?

Comment [H16]: Where is 2013b?

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Comment [H17]: Different notation?

Comment [H18]: Latin name italic

Comment [H19]: Different notation?

Comment [H20]: Different notation?

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Comment [H21]: Different notation?

Comment [H22]: Different notation?

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**Comment [H23]:** Year sequence?

**Comment [H24]:** Different notation?

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